Express Mail No. [illegible]37617224US

Attorney Docket No. STL 10506.00
M & G No. 30874.122USU1

Gap Fly Height Sensing Using Thermal Load Response

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Related Applications

This application claims priority of United States provisional application Serial Number 60/325,842, filed September 27, 2001.

Field of the Invention

This application relates generally to fly height measurement, and more particularly to a method and apparatus for measurement of head fly height using thermal load response.

Background of the Invention

Storage capacity governs the amount of data a user can store on a computer. Adding storage capacity without increasing size means a more dense radial spacing of tracks on disc drives. As a result, the read/write head element's magnetic sensitivity must also increase, which makes the manufacturing process even more demanding and acceptance testing more critical.

Conventional magnetic storage devices include a magnetic transducer or "head" suspended in close proximity to a recording medium, e.g., a magnetic disc having a plurality of concentric tracks. An air bearing slider mounted to a flexible suspension supports the transducer. The suspension, in turn, is attached to a positioning actuator. During normal operation, relative motion is provided between the head and the recording medium as the actuator dynamically positions the head over a desired track. The relative movement creates a lifting force. A predetermined suspension load counterbalances the lifting force so that the slider is supported on a cushion of air. Airflow enters the leading

edge of the slider and exits from the trailing end. Typically, the transducer resides toward the trailing end, which flies closer to the recording surface than the leading edge.

The recording medium holds information encoded in the form of magnetic transitions. The information capacity, or storage density, of the medium is determined by the transducer's ability to sense and write distinguishable transitions. An important factor affecting storage density is the distance between the transducer and the recording surface, referred to as the fly height. It is desirable to fly the transducer very close to the medium to enhance transition detection. Fly height stability is partially achieved with proper suspension loading and by shaping the air bearing slider surface (ABS) to obtain desirable aerodynamic characteristics.

Another important factor affecting fly height is the slider's resistance to changing conditions. An air bearing slider is subjected to a variety of changing external conditions during normal operation. Changing conditions affecting fly height include, for example, change in the relative air speed and direction, pressure changes and variations in temperature. If the transducer fly height does not stay constant during changing conditions, data transfer between the transducer and the recording medium may be adversely affected. Fly height is further affected by physical characteristics of the slider such as the shape of the air bearing surface. Careful rail shaping, for example, will provide some resistance to changes in air flow. To insure compliance with such design criteria the recording heads are typically tested in an apparatus commonly referred to as a fly height tester.

Fly height has typically been measured using optical interferometry. Optical methods require the use of glass discs that have a different roughness and waviness from product discs. Optical methods also require the gap fly height to be extrapolated from measurements of other positions on the slider. Finally, because fly heights are fractions of a wavelength, optical methods are reaching their limits of resolution.

It can be seen that there is a need for improvements in both methods and apparatus for precise measurement of head fly height.

Summary of the Invention

Against this backdrop the present invention has been developed. In one example embodiment, the invention is directed to a system for measuring head fly height in an apparatus with a rotating recording media using thermal load response. The system includes a head having a thermal source and a thermal detector. The thermal sources generate a localized heated volume or heat flux wherein the thermal loss from the head changes as a function of the fly height. The system further includes a sensing arrangement for determining the fly height of the head based on the response of the thermal detector.

In another example embodiment, the invention is directed to a system for measuring a gap in a rotating media system. The system includes a media having a first surface and a head with a second surface disposed opposite the first surface. The system further includes measuring means on the head for measuring the gap between the first and second surfaces.

Another example embodiment is directed to a method for determining fly height of a head flying over a rotating media wherein the head includes a thermal detector and a thermal source. The method includes the steps of energizing the thermal source to provide a heat flux, measuring the temperature of the thermal detector; and calculating the fly height based on the measured temperature.

These and various other features as well as advantages which characterize the present invention will be apparent from a reading of the following detailed description and a review of the associated drawings.

Brief Description of the Drawings

FIG. 1 is an example embodiment of a partial side view of a head and a disc used in a rotating media system.

FIG. 2 is a bottom view of the example head of FIG. 1.

FIG. 3 is an example embodiment of a head including a plurality of thermal detectors.

FIG. 4 is a flow chart illustrating an example embodiment of a method for measuring fly height using a thermal source and a thermal detector.

FIG. 5 is a chart showing inferred thermal detector temperature as a function of fly-height when 50 mA of current is applied to a thermal source with the calculated pole tip fly height as a function of fly-height included on a separate scale.

FIG. 6 is a chart illustrating measured results of a thermal detector resistance change as a function of RPM when 50 mA of current is applied to a thermal source.

Detailed Description

Referring to FIGS. 1 and 2, shown is an example embodiment of a measuring system **100** for determining the gap, or fly height **102,** between a head **120** and a surface **112** of a recording media, such as a disc **110**. Measuring system **100** can be used in a variety of systems, such as disc drives, but is useful in any system where it is desirable to know the fly height **102** of the head **120** over the media surface **112**. Typically, the head **120** rests on surface **112** when the disc **110** is stationary and the head **120** flies above disc **110** when disc **110** is rotating. The height at which the head **120** flies over the surface **112** is the fly height.

Typically, head **120** includes a write element **128** and a read element **126** for writing and reading, respectively, data to and from disc **110**. Elements on the head **120** are in electrical communication with circuitry (not shown) that sends and receives data and other signals and, generally, the circuitry (not shown) controls operation of the disc drive. The head **120** has a face **121** that is located proximately to the surface **112** of the disc **110**. Typically, the read element **126** protrudes from the head **120** toward the surface **112** of the disc **110**. The distance that the read element **126** protrudes from the face **121** of the head **120** is called the pole tip recession **104** (PTR). Generally, the operation most sensitive to the head **120** fly height **102** is reading the data on the disc **110**, and it is most

critical to know the fly height from the read element **126** to the surface **112** of the disc **110**.

Measuring system **100** for determining fly height **102** includes a thermal source **124** and a thermal detector **122**. In the example embodiment shown, write element **128** functions as the thermal source **124** when sufficient current is passed though the write element **128**. The amount of heat generated by the thermal source **124** is a function of the electrical resistance of the write element **128** and the current being passed through write element **128**. The read element **126** functions as the thermal detector **122**. Preferably temperature is measured as a function of electrical resistance of the read element **126**. The present invention determines fly height **102** by measuring the temperature of the thermal detector **122**, which has been found to vary with fly height **102** as will be discussed in more detail hereinafter.

While in the example embodiment shown the thermal source **124** is the write element **128** and the thermal detector **122** is the read element **126**, a separate element for the thermal source **124** other than the write element **128** can be used. Similarly, a separate element for the thermal detector **122** other than the read element **126** can be used, depending on the configuration desired and the amount of space available on the head **120**. For example, the thermal detector **122** could be a separate resistive temperature device (RTD). The sensitivity (change in resistance/change in temperature) of the RTD could be selected so that the output is in a linear range given a set of operating conditions in which the measuring system **100** would be used. Over wider ranges, the output of the RTD could be linearized. One of skill in the art will recognize that a separate thermal sensing arrangement **150** including a resistance measuring and control circuit can be added to circuitry already coupled to the read and write elements **126**, **128**, respectively, to determine the temperature of the thermal detector **122**, and consequently, the fly height **102**. The thermal sensing arrangement **150** includes a device to measure the temperature output variable, preferably resistance. The thermal sensing

device **150** can also include a device to convert the measured temperature directly into a fly height **102** measurement.

An advantage of using a separate device as the thermal source **124** instead of the write element **128** is that the thermal source can be more localized to the gap **103,** and thermal detector **122** is more sensitive to the gap **103** spacing than by using the write element **128** as a thermal source **124**. A separate thermal source **124** also has the advantage that it is less likely to rewrite the disc **110** by imparting sufficient energy to the write element **128** to write data to the disc **110**.

One of skill in the art will recognize that the type and sensitivity of the thermal source **124** and thermal detector **122** can be selected from a wide variety of commonly available items, and selection depends on the particular configuration in which the measuring system **100** is to be used. It is preferable to use a thermal detector **122** that has a change in resistance as a function of changing temperature since the resistance can be measured using components generally present in the type of systems in which the present invention is useful. Resistance can be measured in a number of ways. For example, the resistance can be measured using constant current and measuring the change in voltage. Resistance can also be measured using constant voltage and measuring the change in current. Additionally, resistance can also be measured using constant power and measuring the change in both voltage and current or using a four-point probe method, which uses separate pairs of leads for the current source and voltage measurement. In the example embodiment shown, the current used to energize the thermal source **124** is between 10 and 30 milliamps, though the particular range depends on the type and location of the thermal source **124** used.

Referring to FIG. 3, shown is an example embodiment of a head **320** including multiple thermal detectors **322**. While one thermal detector **322** is generally sufficient to measure the fly height of the head **320** or the read element, placing multiple thermal detectors **322** on the head **320** allows other parameters to be measured. For example, pitch and roll attitude could all be measured using properly positioned thermal detectors

322. In the example embodiment shown, pitch can be measured by determining the localized fly height of the head **320** containing each thermal detector **322**. In a first row **330** oriented along the head **320** in the direction of relative motion between the head **320** and the disc as shown by arrow T, each thermal detector **322** will be at a different height depending on the pitch of the head **320**. The pitch can be determined by knowing the angle formed due to each sensor being at a different height over the surface of the disc. Roll of the head **320** can be determined in a similar fashion using the row of thermal detectors **322** running in a second row **332** perpendicular to the direction arrow **T** of relative motion between the head **320** and the rotating disc.

One of skill in the art will recognize that as many parameters can be measured by using a number of thermal detectors **322** at least equal to the number of parameters that are desired to be determined. Since the relative location of each thermal detector **322** on a head **320** will be known (as part of the design and manufacturing criteria for each head **320**), a system of equations approximating each of the measured parameters can be solved simultaneously to yield the desired results. Additionally, a thermal sensing circuit can be formed that incorporates the thermal source and thermal detector **322** into a single apparatus.

The use of the measuring system **100** described above depends on using a parameter that varies with a change in temperature, such as resistance. For example, in using resistance of a thermal detector **322** to determine temperature, the resistance of most conductors increases with temperature. Over small temperature ranges, the sensitivity varies linearly with temperature. The resistance typically increases with temperature for materials used for both the read and write elements.

The measurement system of the present invention utilizes principles of heat or thermal transfer. Thermal transfer is typically characterized as one or a combination of conduction, convection, and black body radiation.

Referring to FIG. 2, in the case of loss through the gap **103** between the head **120** and the surface **112** of the disc **110**, an additional quantum mechanical loss mechanism is

also present since the gap height is typically less than the thermal wave length of radiated heat. To a first order approximation, the thermal transfer from the flying read element **126** to the disc **110** due to this close proximity will fall off as a function of the exponential power of the fly height **102**.

Referring to FIGS. 5 and 6, these combined effects are demonstrated. FIG. 5 shows the calculated gap fly height **102** plotted on a log scale to show the exponential relationship. In the normal convective heat transfer regime, the thermal transfer is generally proportional to the relative velocity between the disc **110** and the head **120**. As shown in FIG. 5, for the thermal loss due to smaller spacings, this is not the case. FIG. 6 shows the read element **126** resistance as a function of the velocity of the disc **110** measured in revolutions per minute or RPM. If the convective losses dominated, then the read element **126** resistance should decrease continuously with RPM at both radii at which it was measured. In addition, the outer diameter resistance should be lower at each RPM because the linear velocity is about twice the inner diameter linear velocity.

A method to measure indirectly the fly height **102** by measuring the change in temperature of a thermal detector **122** when a thermal source provides a heat source is also disclosed. As can be seen in FIGS. 5 and 6, the thermal transfer between the head **120** and the disc **110** is a sensitive function of fly height **102**.

Referring to FIG. 4, shown is a flowchart of an example embodiment of a method of determining fly height. When using a thermal detector that uses resistance change to measure temperature, the resistance is read and the temperature of the thermal detector is determined. The thermal source is turned on or energized to provide a heat flux. The thermal source measures the temperature, typically by measuring resistance. The step of measuring the thermal detector response can also include providing sub-writing currents to the writer.

By energizing the thermal source and measuring the temperature of the thermal detector, the fly height can be determined. A look-up table based on empirical data, such as that shown in FIGS. 5 and 6, can be used to determine fly height. Circuitry can also be

used to accomplish the same result. It is well within the knowledge of one of skill in the art to design circuitry to determine fly height based on a particular arrangement of thermal detectors on the head and the parameters that are desired to be measured. In addition to energizing the thermal source in a static manner, the thermal source can be cycled in a variety of waveforms. The phase delay and amplitude of the thermal detector signal will be sensitively dependent on the geometry of the devices and the gap spacing. In addition to varying the thermal source, the thermal detector can be energized with a variety of waveforms in order to optimize the response with respect to the thermal source.

While the measuring system has been described in reference to a disc drive system, it is useful in any system where it is desirable to measure fly height, such as optical recording (CD, DVD, and other systems). Additionally, mechanical systems, such as spindle motors, brakes, and precision tooling, with close tolerances (on the scale of less than 100 nm) could also incorporate the measuring system.

It will be clear that the present invention is well adapted to attain the ends and advantages mentioned as well as those inherent therein. While presently preferred embodiments have been described for purposes of this disclosure, various changes and modifications may be made which are well within the scope of the present invention. Numerous other changes may be made which will readily suggest themselves to those skilled in the art and which are encompassed in the spirit of the invention disclosed and as defined in the appended claims.